The Powers of Fault Tree Analysis

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Fault Tree Analysis: a Systematic and Stylized Deductive Process

- An *undesired event* is defined
- The event is resolved into its *immediate causes*
- This resolution of events continues until *basic causes* are identified
- A logical diagram called a *fault tree* is constructed in the process of carrying out the analysis

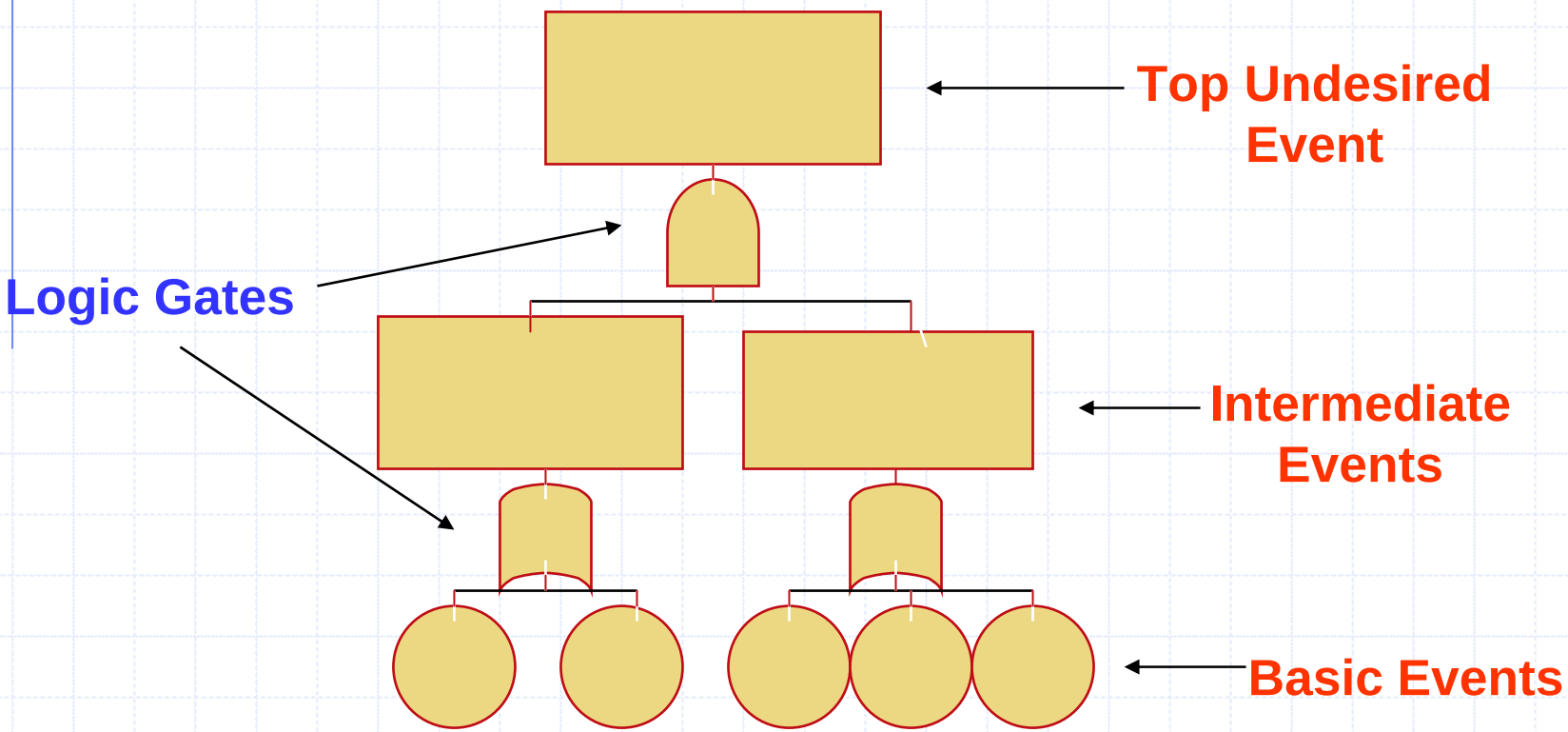
Why Fault Tree Analysis (FTA) is carried out

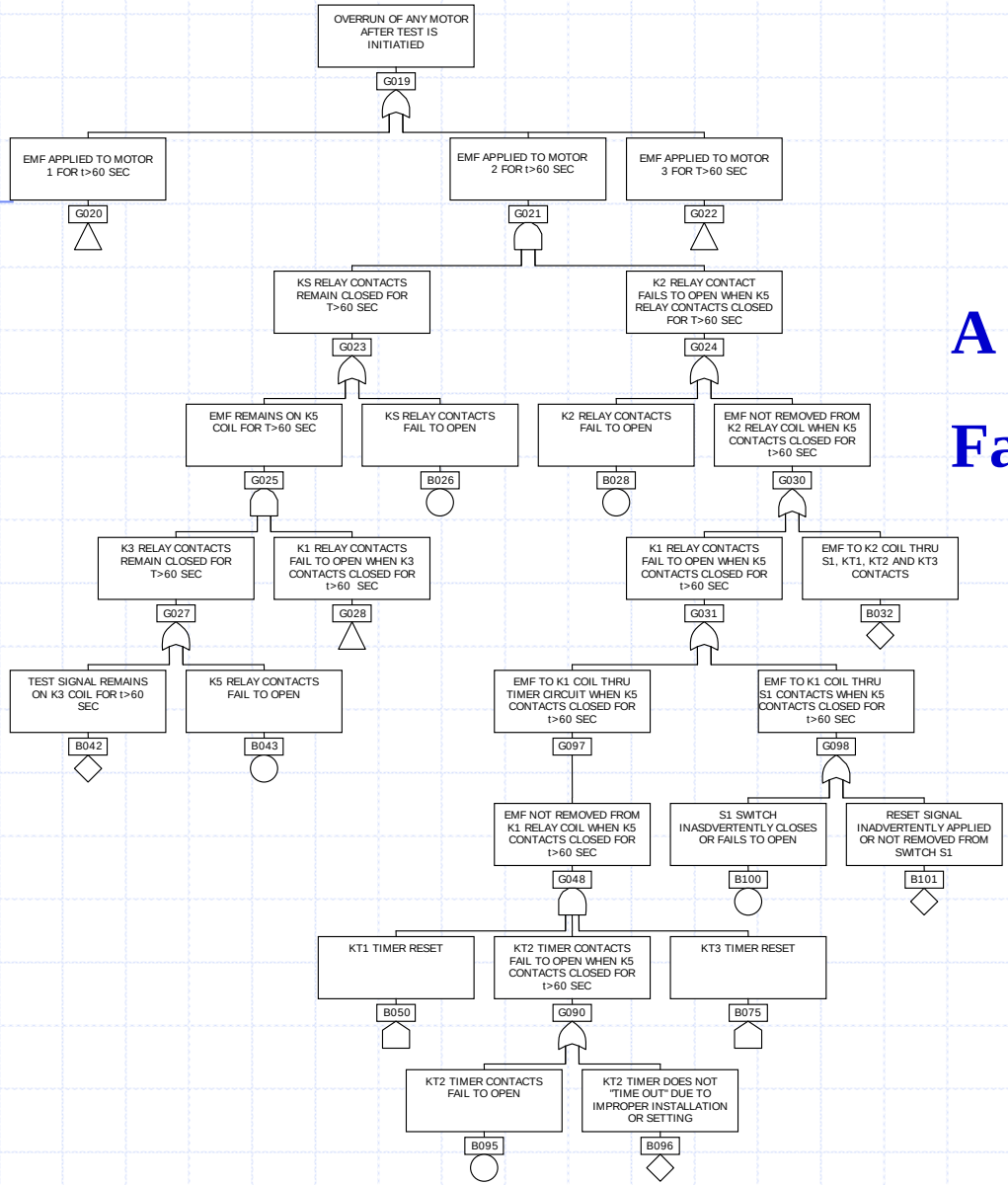
- To gain an understanding of the system
- To document the failure relationships of the system
- To exhaustively identify the causes of a failure
- To assure compliance with requirements or a goal
- To identify any weaknesses in a system
- To prioritize contributors to failure
- To identify effective upgrades to a system
- To optimize operations and processing
- To quantify the failure probability and contributors

The Fault Tree

- FTA produces a *Fault Tree.*
- The fault tree is the *logical model* of the relationship of the undesired event to more basic events.
- The *top event* of the fault tree is the undesired event.
- The *middle events* are intermediate events.
- The bottom of the fault tree is the causal *basic events* or *primary events*.
- The logical relationships of the events are shown by logical symbols or *gates*.

Basic Fault Tree Structure





A Typical Fault Tree

Applications of FTA

- Prioritization of Contributors for Resource Allocation
- Development of a Design
- Determination of Effective Tradeoffs
- Resolution of Causes for Mishap Analysis
- Demonstration of Compliance with Single Failure Criteria
- Establishment of Contingency Criteria
- Monitoring and Tracking of Performance

The Power of FTA in Prioritizing Failure Contributors

- Each basic event in the fault tree can be prioritized for its importance to the top event
- Different importance measures are obtained for different applications
- Basic events generally are ordered by orders of magnitude in their importance.
- In addition to each basic event, every intermediate event in the FT can be prioritized for its importance
- As a general rule, less than 20% of the contributors result in more than 90% of the risk.

Basic Fault Tree Importance Measures

FV Importance = Relative contribution to the system failure probability from a component failure

RAW = Factor increase in the system failure probability when a component is assumed to be failed

RRW = Factor decrease in the system failure probability when a component is assumed to succeed

FV Importance = "Fussell-Vesely Importance"

RAW = "Risk Achievement Worth"

RRW = "Risk Reduction Worth"

Basic Causal Importances for a Monopropellant System

Basic Causal Event	FV Importance (Contribution)	RRW Factor (Reduction)	RAW Factor (Increase)
Human Error Failure to Open Switch S3	99.3%	143	100
Timer K6 Fail to Time Out	86.7%	7.5	43
Relay K6 Fail to Open	13%	1.15	43
Switch S3 Fail to Open	0.5%	1.01	100
Isolation Valve IV2 Fail to Close	0.3%	1.00	13
Relay K3 Fail to Open	0.3%	1.00	1.00
Isolation Valve IV3 Fail to Close	0.01%	1.00	1.00

Uses of the Importance Measures

- Focus system safety on the top contributors (FV)
- Review possible relaxations for the lowest contributors (FV, RAW)
- Focus on upgrades having the greatest improvements (RRW)
- Define contingency measures to be consistent with the failure impact (RAW)
- Establish assurance requirements to be consistent with their importance (FV, RAW)

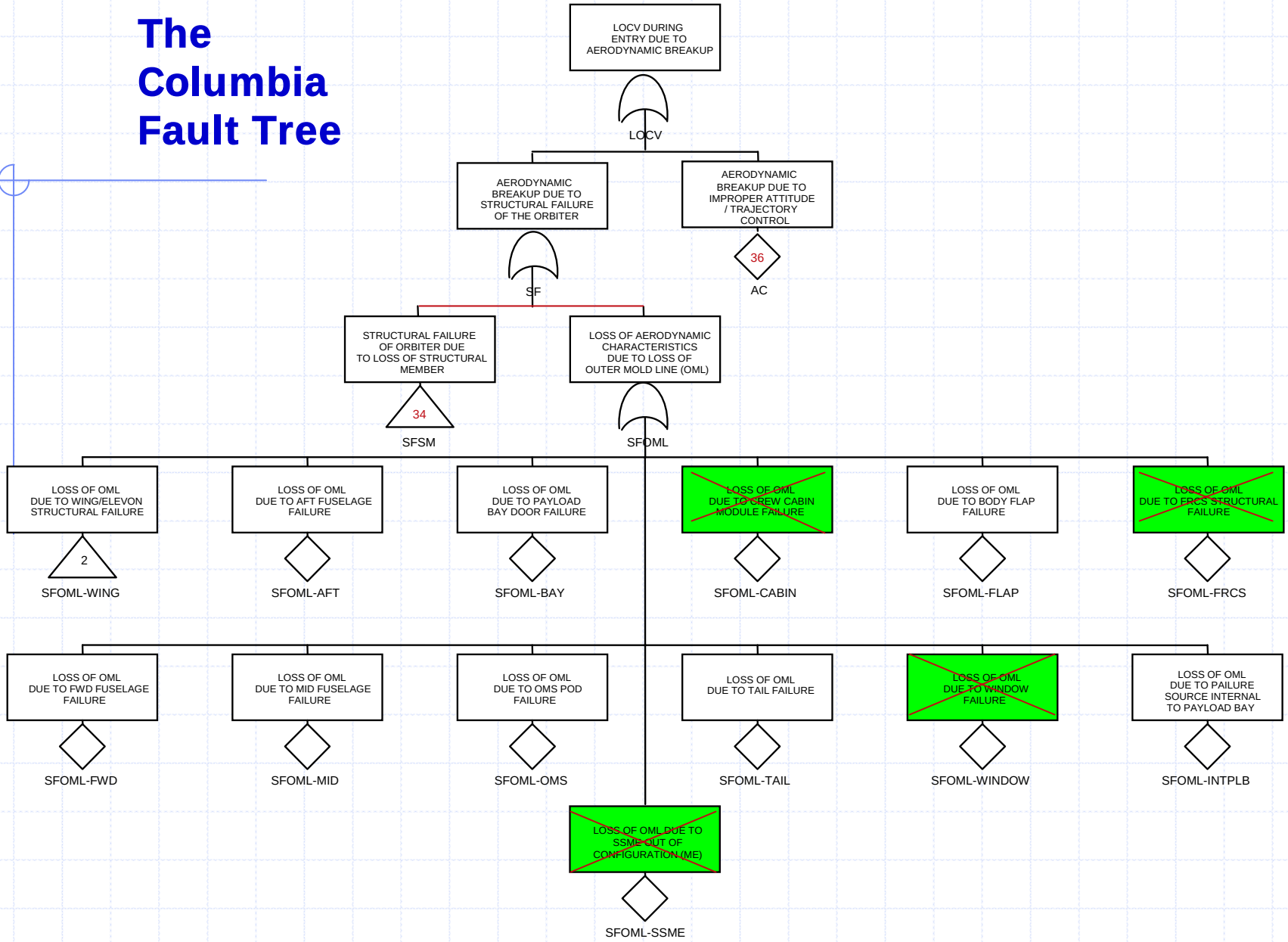
Examples of Importance Evaluations in the Space Shuttle PRA

- Over a million individual events are modeled in the Shuttle PRA and 97% of the calculated risk resides in approximately 308 events.
- Approximately 15% or more of the calculated risk is due to fluid leaks that lead to fire and explosion. This can change based on current updating of the Shuttle PRA
- Abort risk is insignificant to mission risk (<1%).

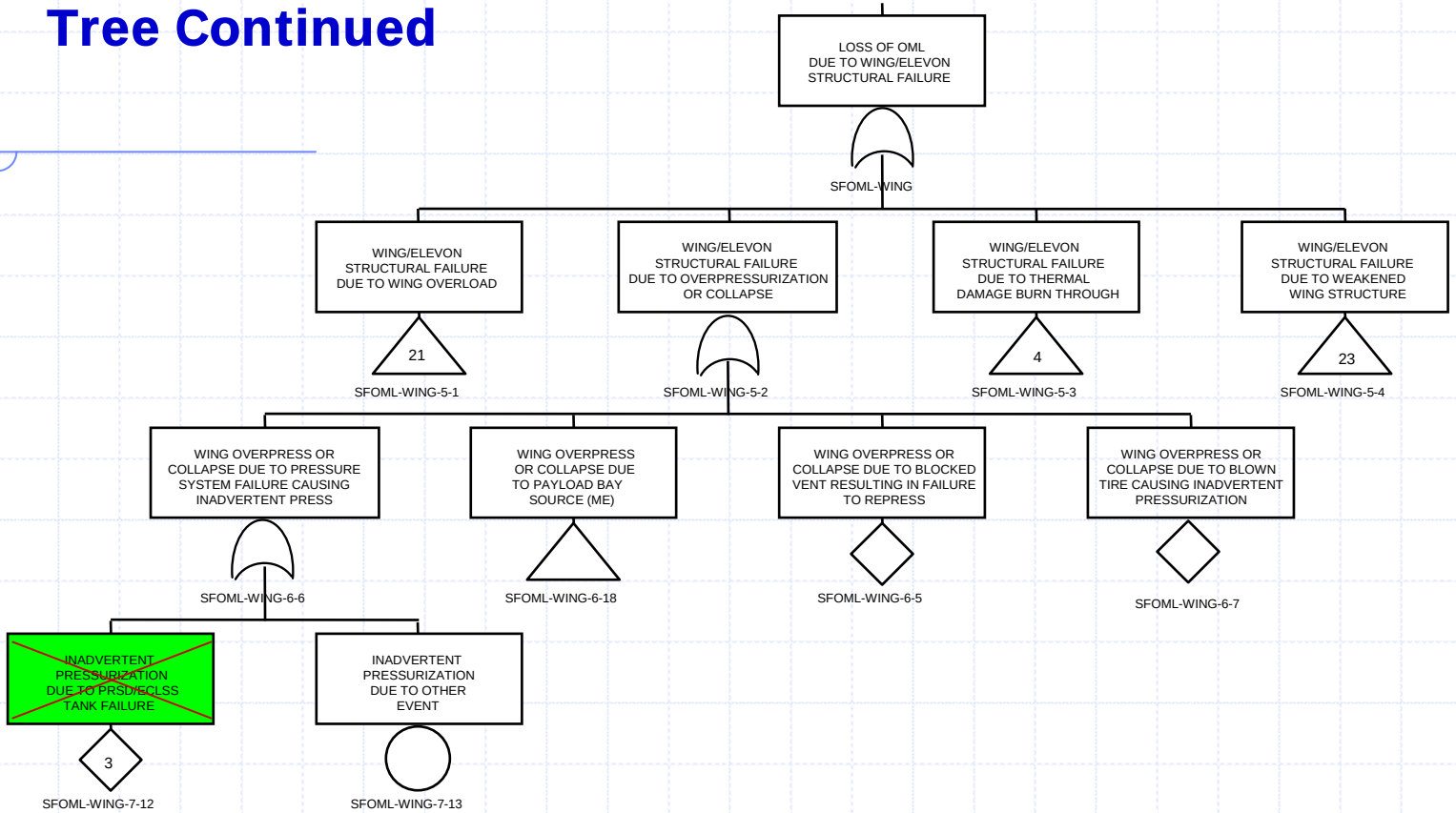
The Use of FTA in Mishap Analysis

- The accident scenario is constructed for the mishap
- System failures (pivotal events) are identified which resulted in the mishap
- A fault tree is constructed for each system failure to resolve the basic events involved
- Root cause analysis is carried out by further resolving a basic event into its root causes
- The basic events and root causes are dispositioned into their importances and actions required

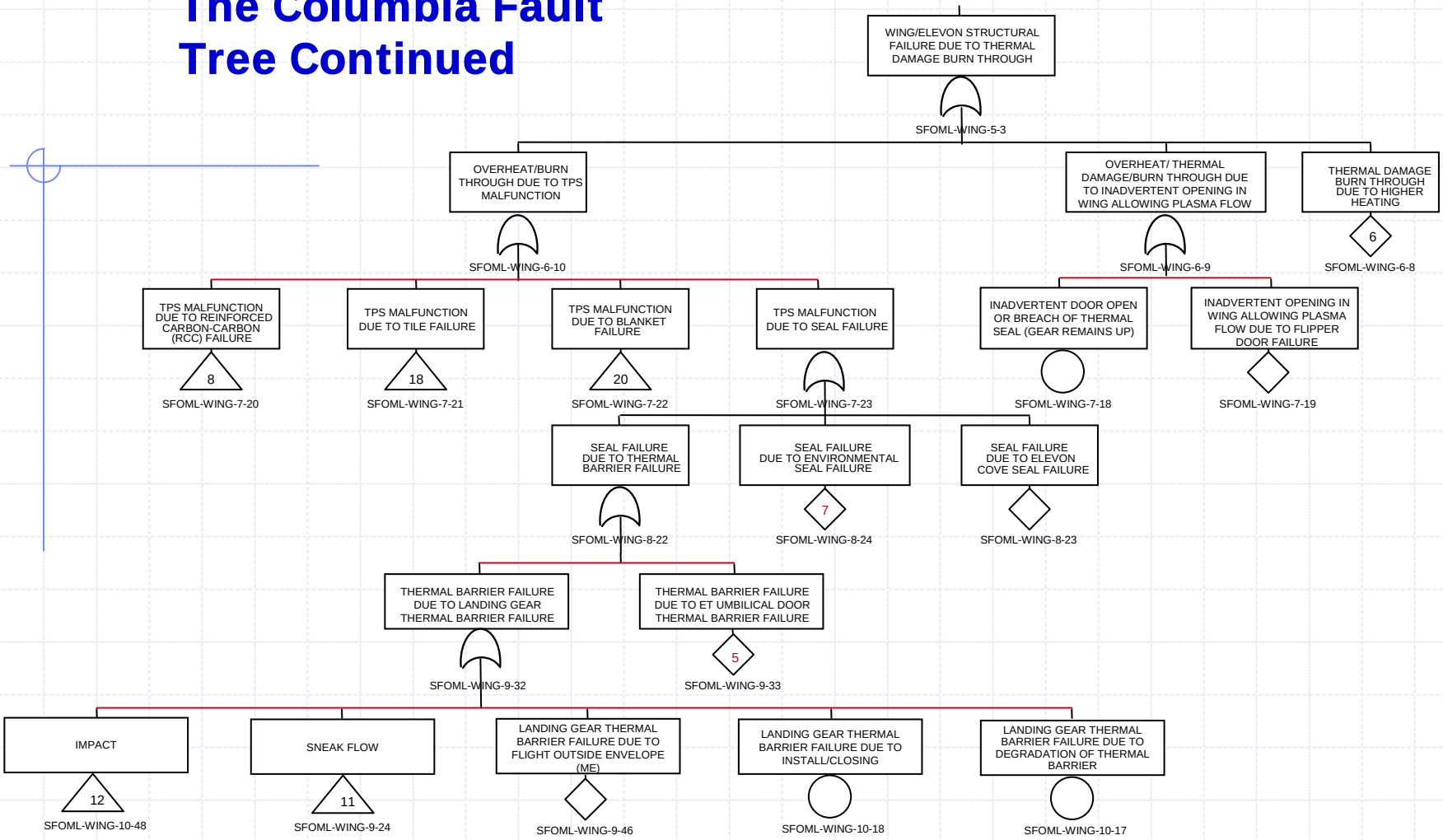
The Columbia Fault Tree



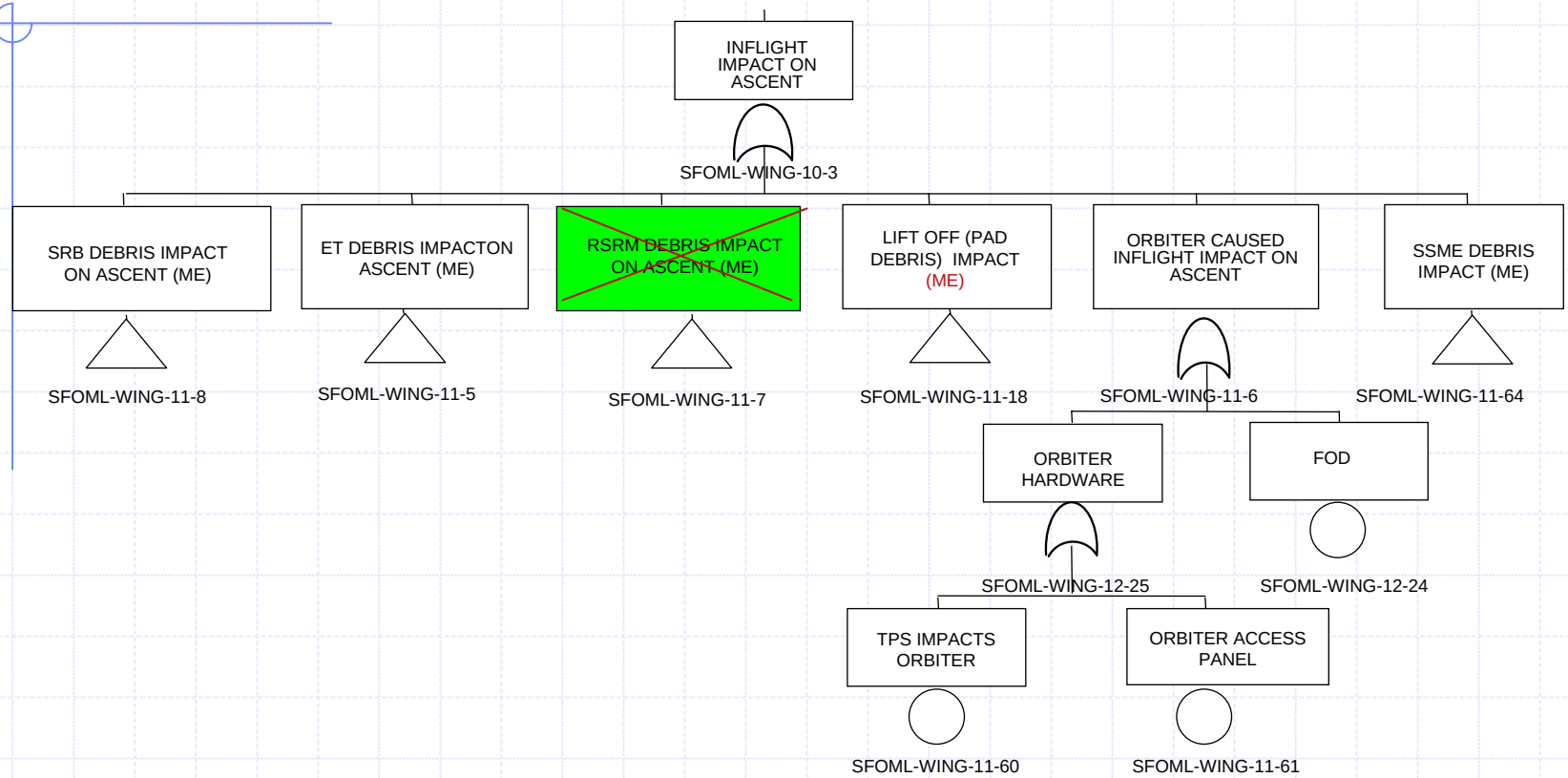
The Columbia Fault Tree Continued



The Columbia Fault Tree Continued



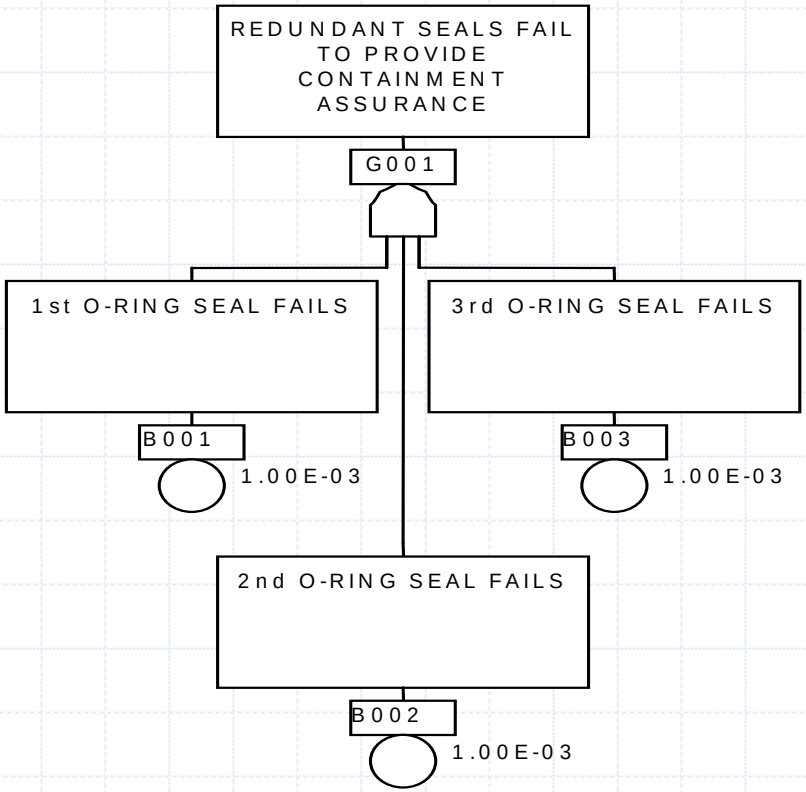
The Columbia Fault Tree Continued



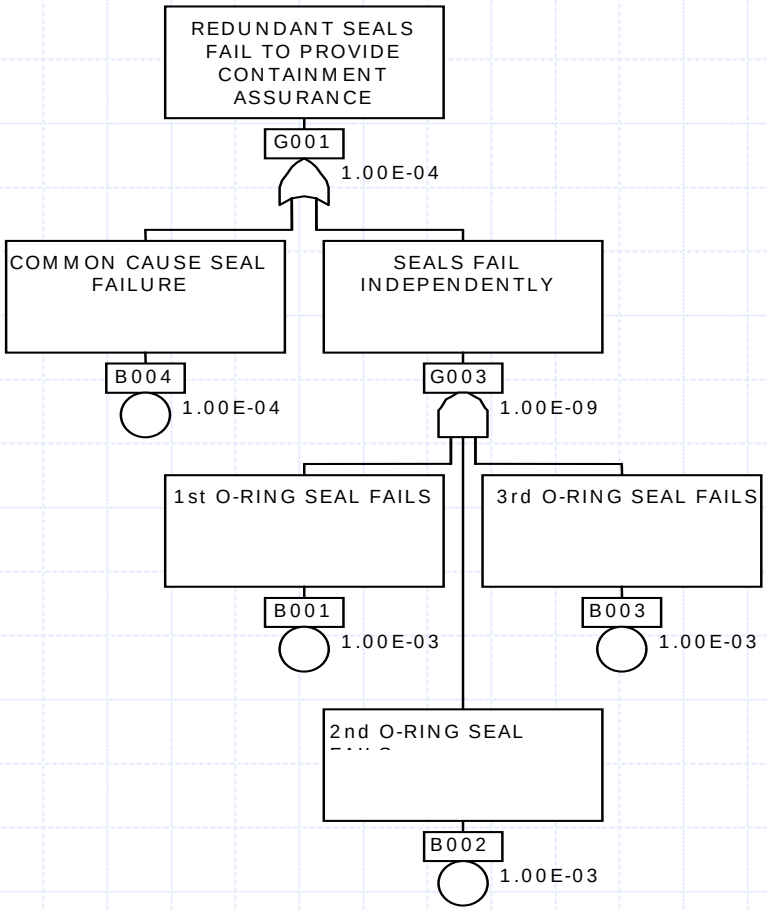
The Use of FTA in Design

- To evaluate a Design, a top level fault tree is developed
  - Functional level
  - System level
  - Subsystem level
- Tradeoffs are carried out
  - Alternative functional capabilities
  - Alternative redundancies
- Allocations are performed
  - System requirement into subsystem requirements
  - Subsystem requirements into component requirements

Redundant Seal Design Allocation Considering Independent Failures



Redundant Seal Design Allocation Including Common Cause Failures



The Fault Tree as a Master Logic Diagram

- The Master Logic Diagram (MLD) is a fault tree identifying all the hazards affecting a system or mission
- The Master Logic Diagram can also be called a Master Hazards Diagram (MHD)
- The MLD or MHD is developed using fault tree logic
- The basic events of a system MHD are the hazards that can initiate component failures or increase their likelihood
- The basic events of a mission MLD are the hazards that are the initiating events of potential accident scenarios

Extending a System Fault Tree to a Master Hazard Diagram (MHD)

- The top event is defined as a system failure event
- The fault tree is developed to the basic component level
- Each component failure is further resolved into hazards and conditions that can cause failure or increase its likelihood
- The resulting system MHD identifies the hazards affecting the system and their consequences
- Of particular importance are single failures and hazards affecting multiple redundant components

Ranking the Criticality of Hazards Using FTA

- Each hazard is linked to a basic event or events on the fault tree
- Equivalently each hazard is linked to the basic events in the minimal cutsets
- The criticality of the hazard is the likelihood of the hazard times the importance of the basic event
- The component importance is determined from the FTA
- The likelihood is determined from the hazard analysis

Hazard Criticality=Likelihood x Importance of Components Affected

MIR HABITABILITY

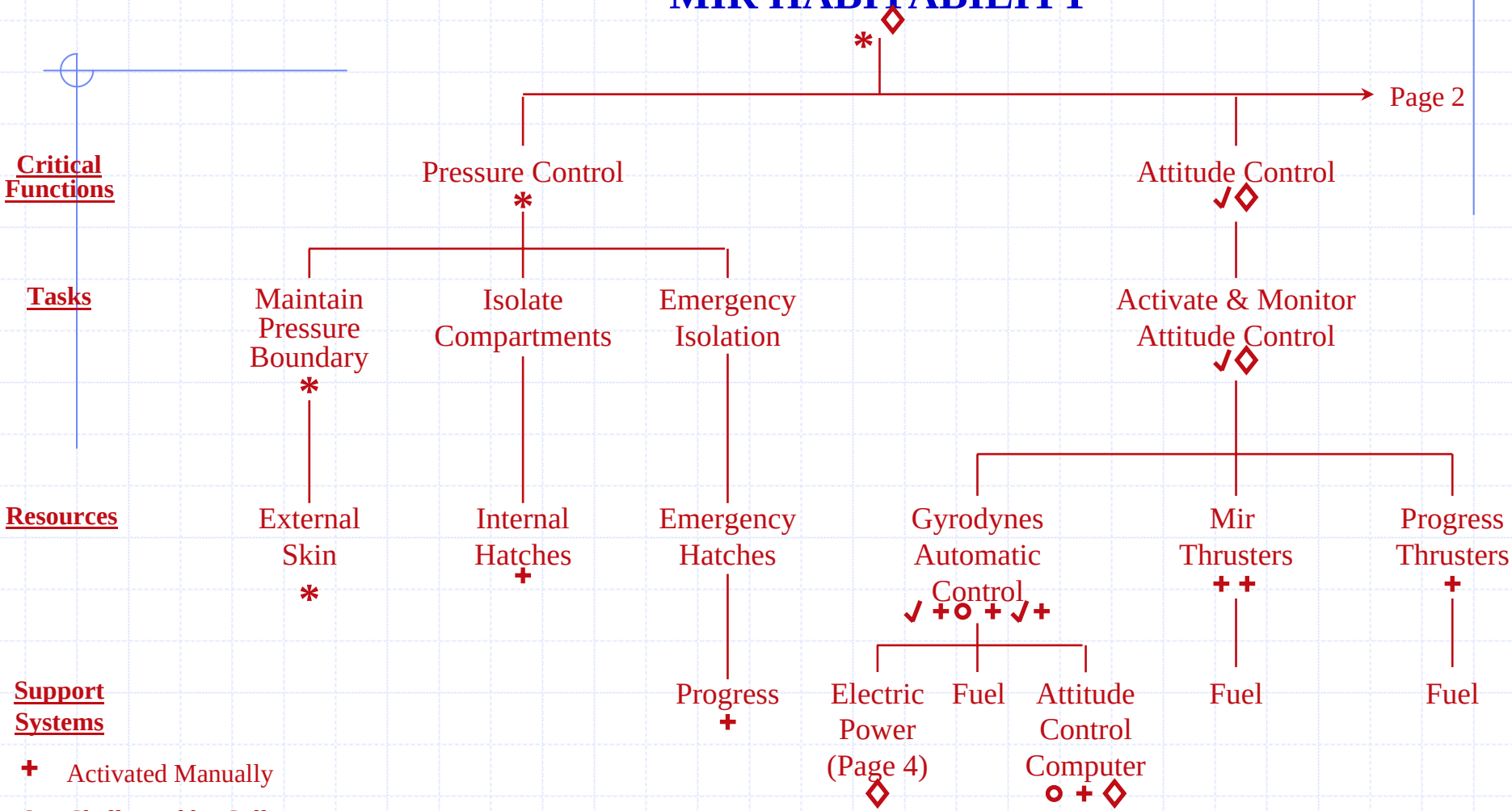
Mission

Critical Functions

Tasks

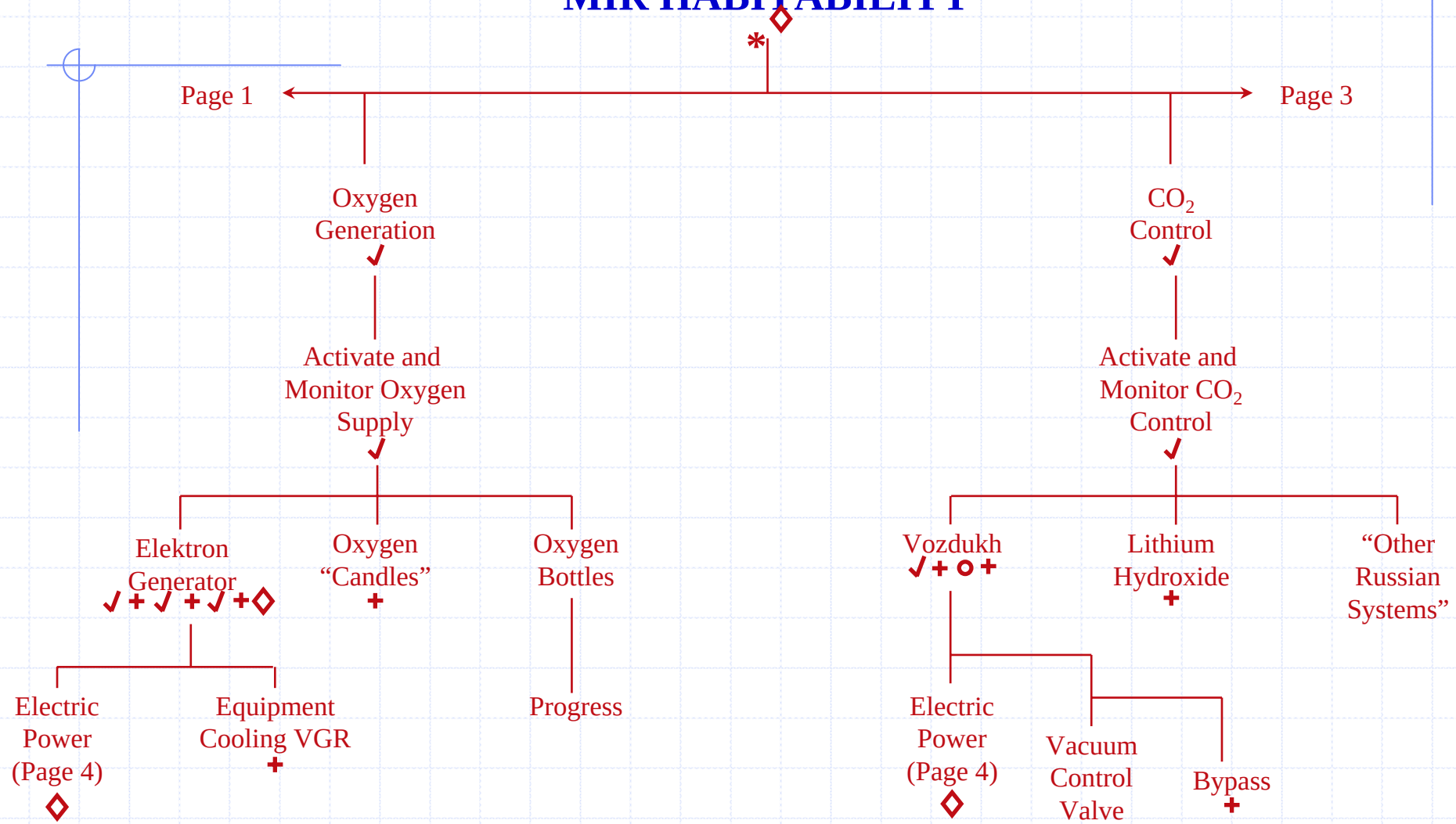
Resources

Support Systems



+ Activated Manually
* Challenged by Collision
✓ Challenged by Manual Action
o Equipment Failure
◇ Disabled/Challenged by Human Error

MIR HABITABILITY



The Mirror Success Tree (ST)

- A Success Tree (ST) identifies all the ways in which the top event *cannot* occur
- The ST is the *complement* of the FT
- The ST is the *mirror* of the FT
- The ST is useful in showing the explicit ways to *prevent* the occurrence of the FT
- The ST is the *success space* twin of the FT

Developing the Success Tree from the Fault Tree

- Complement the top event to a NOT event
- Complement all intermediate events to NOT events
- Complement all basic events to NOT events
- Change all AND gates to OR gates
- Change all OR gates to AND gates
- The tree is now the ST
- The minimal cut sets of the ST are now called the minimal path sets

The Minimal Path Sets Define the Success Modes of the System

- A minimal path set is the smallest number of events which if they all do not occur then the top event will not occur
- If the events in one path set are prevented to occur then the top event will be guaranteed to not occur
- The minimal path sets are the totality of ways to *prevent* the top event based on the fault tree
- The minimal paths should be determined as a part of a fault tree analysis

FTA Project Management Tasks (1)

- Define the FTA
  - Top Event
  - Scope
  - Resolution
- Assemble the project Team
  - FT analyst
  - System engineering support
  - Data support
  - Software support
- Define the FTA Operational Framework
  - Assemble the as built drawings
  - FT naming scheme
  - Interfaces/Support to be modeled
  - Software to be used

FTA Project Management Tasks (2)

- Assemble the data
  - Generically applicable data
  - Specifically applicable data
- Prepare the software package
  - Familiarization
  - Test problems
- Keep a log on the FTA work
  - Operational and design assumptions
  - Events not modeled and why
  - Success and failure definitions
  - Special models and quantifications used

FTA Project Management Tasks (3)

- Review the work at stages
  - FT construction
  - Qualitative evaluations
  - Quantitative evaluations
- Check and validate the results
  - Engineering logic checks
  - Consistency checks with experience
- Prepare and disseminate the draft report
  - Conclusions/findings
  - FTA results
  - FTs
  - Software inputs/outputs
- Obtain feedback and modify and final report
  - Disseminate the report
  - Present findings

Reference

- “Fault Tree Handbook with Aerospace Applications’, Version 1.1, NASA Publication, August 2002.